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THE UNIFORM APPLICATION OF ALARA TO ALL RADIATION WORKERS

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ABSTRACT

New information on the dosimetry and epidemiology of the atomic bomb survivors suggests that risk estimates may have to be revised upwards. This has focussed increased attention on the ALARA principle.

The point of view of the ICRP is that the operation of the ALARA principle, rather than dose limits, is the driving force in keeping average radiation doses for most categories of atomic radiation workers well below the limit. According to the NDR the overall average annual dose is about 0.7 mSv (1985 data), compared to the annual limit of 50 mSv, and so the point of view of the ICRP is in agreement with the facts. Whether there is a cause-effect relationship however, between the ICRP promotion of ALARA, and low average doses in Canada, is not so clear.

In practice, the optimization process required for ALARA varies a great deal between different sectors of the "nuclear industry" interpreting this term broadly to include all licensed uses of radioactive material. For instance, the power utilities have developed procedures for comparing in detail different dose reduction options. Similarly, uranium mine operators have applied optimization techniques to questions concerning ventilation and shielding of ore trucks. Missing from this list however, is the use of a formal optimizing technique in the medical and research uses of radioactivity or radiation. Nonetheless, average annual doses to these workers are quite low, about 0.5 mSv.

An alternative approach to optimization calculation has been suggested, which entails the identification of sub-groups of workers with substantially higher doses to first discover the reasons for the higher than average doses, and to develop means to reduce them to the overall average.

For instance, it is well known that maintenance mechanics in nuclear reactors, by the very nature of their jobs, have more potential for higher dose, and this is shown in the dose data. The utilities are developing procedures to reduce the maintenance mechanics' doses.

If the same analysis is applied to medical workers, it is seen that isotope technicians and therapeutic radiology technicians have average doses well above the overall average. The feasibility of some form of optimization process for these categories of workers is discussed.

RÉSUMÉ

De nouvelles données sur les caractéristiques dosimétriques et épidémiolo-liques des survivants de la bombe atomique laissent entendre que les estimations de risque doivent peut-être être augmentées, d'où un intérêt accru pour le principe ALARA qui est de maintenir les doses au niveau le plus faible qu'il soit raisonnablement possible d'atteindre.

La Commission internationale de protection radiologique (CIPR) croit que l'application du principe ALARA, plutôt que les limites de doses, est le principe moteur pour maintenir les doses de rayonnements moyennes de la plupart des catégories de travailleurs sous rayonnements bien en deçà de la limite. Selon le Fichier dosimétrique national, la dose annuelle moyenne générale était d'environ 0,7 mSv en 1985, comparativement à la limite annuelle de 50 mSv, ce qui montre que les faits confirment la position de la CIPR. Il reste cependant qu'il n'est pas possible de dire s'il existe une relation cause-effet entre le principe ALARA que préconise la CIPR et les doses moyennes faibles au Canada.

En pratique, le processus d'optimisation requis par le principe ALARA varie beaucoup d'un secteur à l'autre de l'industrie nucléaire qui l'interprète assez largement pour comprendre toutes les utilisations autorisées de matières radioactives. Par exemple, les services publics ont établi des procédures pour comparer en détail les différentes options pour réduire les doses. De même, les exploitants de mines d'uranium appliquent des techniques d'optimisation aux problèmes de ventilation et de blindage des camions de minerai. Malgré tout, la liste ne comprend pas de techniques d'optimisation officielles en médecine et en recherche. Néanmoins, les doses annuelles moyennes de ces travailleurs est plutôt faible, soit environ 0,5 mSv.

Une autre approche a été suggérée pour calculer l'optimisation en identifiant les sous-groupes de travailleurs qui ont reçu des doses moyennes beaucoup plus élevées que la moyenne générale des travailleurs. On s'intéresse tout d'abord à ces groupes pour découvrir surtout les causes de ces doses plus élevées que la moyenne et pour mettre au point des mesures pour les réduire à la moyenne générale.

On sait très bien, par exemple, que les spécialistes de la maintenance dans les réacteurs nucléaires, par la nature même de leur travail, sont susceptibles de recevoir des doses plus élevées, et cette situation ressort bien des données sur les doses. Les services publics sont en train de mettre au point des procédures pour réduire les doses de ces spécialistes.

Si on applique la même analyse aux travailleurs médicaux, on constate que les techniciens d'isotopes et de radiologie thérapeutique reçoivent des doses moyennes bien supérieures à la moyenne générale. Le rapport traite de la faisabilité d'un processus d'optimisation quelconque pour ces catégories de travailleurs.

THE UNIFORM APPLICATION OF ALARA TO ALL RADIATION WORKERS

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INTRODUCTION

The ICRP system of dose limitation consists of three components(1):

a) Justification
b) ALARA (optimisation)
c) Dose Limits (protection)

Justification means that any practice involving radiation dose must produce a net benefit. Protection means that no worker should be allowed to exceed the limits, since the limits represent a risk generally considered unacceptable. ALARA (as low as reasonably achievable) or optimization means that radiation doses from a practice should be reduced to such a level that further reduction becomes unreasonable. How this level is determined is the subject of this paper.

A further point should be made about dose limits. The recent publication of the RERF report(2) on the revised dosimetry of the atomic bomb survivors has strongly suggested that risk estimates, i.e. the risk of developing fatal cancer per unit dose received, should be revised, and the figure that seems to be gaining credence is of the order of 2(3), i.e. the risk factor should go from 10^{-2}/Sv to about 2×10^{-2}/Sv. This implies that the present limits should be avoided with more vigor than they are at present, and it has even been recommended by the NRPB(4) that while the limits themselves should not change, individual <u>average</u> annual doses should be kept to 15 mSv.

To put this figure in perspective, the latest annual report of the National Dose Registry(5) gives an overall average dose for all monitored radiation workers (note that this group is much larger than the AECB-defined "Atomic

Radiation Worker" category, since it includes X-ray workers and many people that work with radiation to a lesser extent than required to class them as ARWs) of 0.64 mSv per year. If we look at subcategories, we find annual doses as shown in table 1.

Table 1

Weighted Average Doses for 1985

Industrial and Research	1.03 mSv
Medical	0.29 mSv
Mines	2.12 mSv
Reactors	1.46 mSv

It will be noted that all the group averages are below 15 mSv. There are however, some subgroups that have significantly higher averages than the overall, and than their major grouping. It is claimed that the low level of actual doses, in comparison to the limit, is due to the influence of the ALARA principle. In order to explore the validity of this claim, the ALARA principle must be defined.

ALARA OR OPTIMIZATION

In much current literature, the ALARA acronym (as low as reasonably achievable) has been replaced by the term optimization, because this term carries an implication of an approach to defining the word "reasonable".

Since 1984, ICRP Committee 4 has had a task group producing a report on all methods of optimization. This report will eventually replace ICRP37, (6) which dealt only with cost benefit analysis (CBA). ICRP37 in fact, has been accused of giving optimization a bad name, since it implied that optimization meant CBA and only CBA. The new report is expected to be at pains to dispel this impression, and to show that several other techniques and approaches may be used for optimization.

METHODS

The task force chairman, G.A.M. Webb, recently gave an informal progress review, (7) although he emphasized that the ideas presented were not to be considered official ICRP policy. He presented a very good survey of optimization methods that are currently available, which are listed in table 2.

Table 2

1. Cost-effectiveness analysis
2. Differential cost-benefit analysis
3. Cost-benefit analysis
4. Multi-attribute utility analysis
5. Multi-criteria outranking analysis

In general these methods are as complex as their names suggest, but do not despair at this point. I will try to compare them briefly, in qualitative terms, although you are warned that the more detailed descriptions that Webb provided contain differential equations.

All the methods attempt to compare different options in a quantitative way, and are elaborations of cost-benefit analysis (CBA).

CBA is based on a well established principal of welfare economics known as the a Pareto improvement criterion*. This states that a Pareto improvement is a change that makes at least one person better off, and none worse off. In economic theory, such changes should obviously be carried out.

CBA attempts to identify a Pareto improvement by adding up the economic cost of each proposed option and the cost of its associated detriment. Whichever option has the lowest total cost is the one that is the optimum, where optimum is defined as the best option within the given constraints. In order to do CBA, all factors must be expressed in the same units, i.e. dollars. This means that the detriment must be expressed in dollars, and detriment in radiation protection is the number of cancer deaths or severe genetic disorders.

To digress a little at this point it should be pointed out that throughout this analysis, the basic assumption is the linear non-threshold hypothesis of radiation dose versus effect. This means that a given dose of radiation will produce a detrimental effect at the rate of 10^{-2} per Sv per year (Pre-RERF figure). The same number of effects will be produced, however many people this dose is distributed over, even if each individual dose is extremely low, e.g., a small fraction of natural background. This assumption has often been challenged (8), but no good evidence exists on which it can be rejected. In fact, current thinking in some circles is that, once an individual's natural radiation dose is taken into account, i.e., about 50 mSv by age 25, he is well into the linear portion of the curve, and so, the smallest additional dose will indeed carry a proportional increase in risk.

CBA requires that a dollar value be put on the detriment, which leads immediately to the "value of a life" controversy, which sets the "feelers" against the "thinkers". It is not difficult to look at what is actually spent by authorities on, say, highway safety and divide by the number of lives potentially saved, and come up with a value. This has been done in some

* Wilfredo Pareto was an Italian Economist 1848-1923.

detail by IAEA, ICRP, and others (9) considering many other factors, and they arrived at a value of $3,000 - $20,000 per man Sv, derived from the cost of a cancer death of around $200,000. Many people, particularly those who perceive themselves to be at risk from radiation, have misgivings about such calculations.

Other problems with CBA include the inherent uncertainties in this type of calculation and the fact that if more than a limited number of factors are considered, the method becomes very cumbersome. To overcome the latter problem, multi-attribute methods may be used. These are capable of summing up a number of factors, even when these factors are non-linear functions of cost.

The forthcoming ICRP publication will no doubt explain all these methods in excruciating detail. It is also expected to make clear that such methods are not required in all circumstances, and that in many cases informal or intuitive procedures may be used.

An informal method is one in which it can easily be shown that real dose reduction can be accomplished at a cost which is obviously small compared to other operational or capital costs. An intuitive one is where, for instance, it is obvious that a change in operational method, which has minimal or zero cost, will obviously reduce dose. This is otherwise known as common sense.

THE NEED FOR OPTIMIZATION

With all the effort already expended on radiation protection, compared to many other occupational hazards it can be (and has been) asked: why bother with optimization, as doses are low enough already?

While in general this is true, there are some categories of radiation worker that accumulate doses higher than the average. Also it is not clear whether the low average doses are due to an explicit use of optimization as claimed by ICRP, or whether they are due to workers following "generally accepted" safe working procedures in working environments that have "generally accepted" radiation protection features.

Whether or not there is a causal relationship between optimization and the doses being actually received by workers, there is an increasing emphasis on optimization. This has been given more impetus by the recent RERF report and resulting suggestions, already mentioned (3), that the risk factor per Sv should be increased by a factor of about 2. This implies that dose limits should be reduced by the same factor, but all the evidence is not yet in for what would be a very major change. Since actual doses are on average so much below the limit, it is felt that it would be far more productive to emphasize optimization than to lower the limits. The AECB, in its proposed amendments to the AEC regulations, will specifically require optimization to be done as part of the licensing process. In some areas, particularly power reactors, much work has already been done, and Ontario Hydro for example has used various optimization techniques to make radiation protection decisions.

In the area of uranium production, the French have done several major studies and the Canadian industry has made a start on optimization.

In the laboratory area, i.e. hospitals and universities, a literature search has shown that very little has been done, in a formal way, although dose reduction techniques have been developed. Examples of optimization in each area are given below.

POWER REACTORS

Ontario Hydro contributed a paper to a 1986 IAEA symposium on optimization of Radiation Protection (10) that described the evolution and application of the optimization of design for nuclear power stations. A simple cost benefit approach is used, with a value of $10,000 per man Sv. Examples of the use of the method are the management of contaminated sewage sludge, the reduction of tritium in heavy water processing, and improvement in post-accident containment venting.

URANIUM MINES AND MILLS

A joint paper by several Canadian uranium mining companies was presented at the same IAEA symposium (11). Again, simple CBA was done to evaluate shielding of trucks carrying high-grade ore. Values of $10,000 and $20,000 per man Sv were used in the calculations. Another example dealt with the decommissioning of a uranium mine, in which five different options were considered, using simple CBA, with a value of man Sv of $10,000. The other example in this paper deals with the ventilation of an underground mine. The method here was to derive the regression equation between ventilation cost and annual average exposures for about 6 years of data. This allowed the cost of further reduction to be estimated at about $2 X 10^6 per man Sv, which was concluded to be excessive, as compared to $10,000 or $20,000 per man Sv. This was a different approach since only one option was considered, and it was assessed by direct comparison to the "standard" value of a man Sv. It is also interesting for two other reasons. First, because the relationship between cost and dose reduction is non-linear, and second because doses to the miners concerned are relatively high, averaging about 40% of the limit. NRPB (12) has recommended that at these levels, the value of a man Sv should be put at about $200,000, i.e., ten times the value used by the uranium mines.

The French have done a lot of work on optimization in uranium mines (13), and they arrive at a cost of dose reduction of $16,000 to $80,000 per man Sv where the maximum individual doses are 70% of the limit. A second study (14) considers several options for reducing radon concentration, which vary from $17,000 to $14 X 10^6 per man Sv for miners with individual doses at the limit. For the $320,000 option, these doses could be brought down to about 30% of the limit. The above description is intended to show that formal optimization studies have been done in Canada and elsewhere for dose reduction in uranium mines.

LABORATORIES

Workers in hospitals and laboratories are the third major category of radiation worker. At the IAEA Symposium in 1986, only one paper on optimization in the medical field was presented, and this low representation

was commented on by the chairman, who pointed out that such papers had been requested.

A short literature did turn up several articles on the subject, most of which were in the British Journal of Radiology (B.J.R.) and Journal of Nuclear Medicine Technology (J.N.M.T.).

The J.N.M.T. articles were not formal optimization studies but rather informal or intuitive applications of common sense to devise simple equipment or procedures, having negligible cost, to provide sometimes quite significant dose reductions, as shown in table 3.

Table 3

Method	Cost	Dose reduction
1. Careful handling of syringes (15)	Zero	Up to factor of 10 for fingertip dose
2. Use of old generator shielding to shield other sources (16)	Negligible	Not stated
3. Detailed measurements of dose rate around ^{131}I therapy patients (17)	Negligible	Not stated
4. Closed, shielded system for oral ^{131}I administration (18)	Negligible	100 to 1000 times less contamination
5. Remote reservoir injection device (19)	Low	Fingertip dose 300-600 times less than with shielded syringe

Of the B.J.R. articles, one (20) is a detailed cost-benefit study on the introduction of remote after-loading equipment for gynecological radiotherapy. Two alternative schemes were examined, using a value of a man Sv of $4,000 for the public (visitors) and $20,000 for staff. The optimal scheme was shown to have a net benefit of $120,000. Another study (21) looks at lead screening for radiodiagnostic staff, and shows that at $20,000 per man Sv, lead thicker than 0.5 mm is difficult to justify, particularly compared to the use of low-dose anti-scatter grids.

Again, the description of these studies is intended to show that such studies have been done, and to show the value of a man Sv that was used.

DISCUSSION

It has been shown that formal optimization studies have been done for two major categories of radiation workers, in power reactors and uranium mines. Radiation doses are, or have the potential to be, large fractions of the limit for these workers. Such formal studies would seem to be appropriate in these cases, since the organisations involved are large. It is also of note that the α values used fall into more or less the same range.

In the medical and laboratory area, doses are usually a small fraction of the limit, and there are a large number of hospitals and laboratories. The resources to do optimization studies are thus limited, and as has been seen from the literature, a "common-sense" approach is often taken. Nevertheless, formal optimization studies would be useful, particularly of a generic type, which could be applied to many nuclear medicine departments.

With regard to compliance with the optimization (or ALARA) requirements in the proposed amendments to the AEC regulations, for power reactors and uranium mines, the formal studies that have been done, suggest that others could be done to cover other aspects of these operations, as required. In the medical and laboratory area, since the approach has been, in general, more informal, it may be sufficient to assume that if average doses are low enough, then

optimization must have occurred. This then requires a definition of "low enough". Returning to the NDR data, the average for all monitored workers is 0.64 mSv per year. The major component groups have averages as already shown in table 1. If these major categories are subdivided, the highest doses in each group are as shown in table 4. It should be remembered that some NDR categories may contain significant numbers of workers who receive essentially zero dose (see NDR annual reports), and in a large group these could mask the presence of small sub-groups with average doses much larger than the overall group average.

Table 4

Sub-Group	1985 (1984) Average Dose (mSv)	% Contribution to Total Collective Dose
Industrial Research:		
Industrial Radiography	3.93 (2.94)	9 (6)
Medical:		
Isotope Technician	2.09 (1.99)	3 (2)
Mines: (no subcategories)	2.12 (2.44)	21 (25)
Reactors:		
Mechanical Maintenance	4.64 (6.22)	9 (11)
Reactor Operations	3.84 (4.92)	9 (12)

Although the isotope technologist category has the lowest average dose in table 4, this average is of the same order of magnitude as the other categories, moreover, internal dose is not included. Also, the contribution

of this category to the total collective dose is significant. If now this category is compared to other medical categories by means of table 5, it is seen that with 4% of the medical population, it contributes about 30% of the collective dose to medical categories. On the other hand, the diagnostic x-ray technologists with about 40% of the population contribute only about 25% of the collective dose.

On this basis, it would appear that there is a need for optimization for this category of worker, although it is realized that few nuclear medicine departments have the resources to perform wide-scale studies. Nevertheless, such a study would be very useful in identifying examples of optimization that could be utilized by many nuclear medicine departments and also in demonstrating to regulators and workers that optimization is being done.

Table 5

Medical Doses 1985

Category	Average Dose (mSv)	Population	% of total Population	Collective Dose (p.Sv)	% of total Collective Dose
Gynecologist	0.85	32	0.15	26	0.44
Isotope Technologist	2.09	856	4.2	1789	30.6
Laboratory Technologist	0.19	2572	12.6	489	8.4
Physicist	0.53	179	0.87	95	1.6
Nurse	0.19	3328	16.3	632	10.8
Physician	0.34	1662	8.1	56	0.96
Diagnostic Rad. Tech.	0.17	8404	41.1	1429	24.4
Therapeutic Rad. Tech.	1.10	518	2.5	570	9.7
Diagnostic Radiologist	0.35	1468	7.2	514	8.8
Therapeutic Radiologist	0.61	132	0.64	80	1.4
Orderly	0.31	1304		170	2.9
		total 20455		total 5850	

Weighted average dose for total medical category = 0.29 mSv.

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